Dynamic Modeling of Marine Bioluminescence and Night Time Leaving Radiance

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LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

OBJECTIVES

Our objectives are to develop the methodology for bioluminescence potential (BL) and bioluminescence leaving radiance (BLw) predictions on scales to 1-5 days, and to understand the coupled bio-optical and physical processes in the coastal zone that governs the variability and predictability of bioluminescence.

APPROACH

Approach is based on joint studies of the marine bioluminescence potential (BL) and Inherent Optical Properties (IOPs) over relevant time and space scales. The physical model is based on the Navy Coastal Ocean Model (NCOM), the biochemical model simulates dynamics of two sizes of phytoplankton, zooplankton, nutrients, ammonium, and detritus pools (Shulman et al., 2011). The BL potential model is based on advection-diffusion-source model, with velocities and diffusivities taken

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from the physical model (Chai et al., 2002; Fujii et al., 2007; Shulman et al., 2011). The proposed research is being significantly leveraged by the interdisciplinary and multi-institutional modeling and field efforts of the NRL BIOSPACE and MURI ESPRESSO projects. Bio-optical, physical observations from the following field programs are being used in this study: AOSN I and II (Moline, 2007 and 2009, Shulman et al., 2003, 2005, 2009); bioluminescence observations from Monterey Bay surveys conducted by Dr. Haddock (Augusts of 2000, 2002, Decembers of 2002 and 2003 and March of 2004); NRL BIOSPACE-ESPRESSO May-June of 2008 experiment; NRL BIOSPACE/MBARI CANON experiment in October 2010. We design predictive experiments when the model is initialized by using a set of BL potential observations. After that we conduct forward in time simulations without assimilation of new observations, in this case the experiments simulate the forecasting of the BL potential. The forecasts are compared to the non-assimilated observations. Bio-optical, physical observations are being used also for verification and interpretation of our numerical experiments results.

WORK COMPLETED

Dynamical, predictive biochemical, physical and bioluminescence potential (BL) models are combined into a methodology for short-term modeling and forecasting of BL potential, Inherent Optical Properties (IOPs) and the nighttime water-leaving radiance (BLw) due to stimulated bioluminescence at depth.

We demonstrated that observed bioluminescent dinoflagellates' avoidance of advection during the upwelling development can be explained by their vertical swimming ability. This mechanism also helps explain the general persistence of dinoflagellates in the upwelling shadow area. We published JGR Oceans paper on this subject. **The paper was selected by AGU Editors as AGU "Research Spotlight".**

Project results were presented at the ONR Marine Mammals & Biology Program Review, April 16-18, 2012, Washington, DC.

Book Chapter (which includes results from this project) has been submitted.

RESULTS

In the upwelling-driven system of Monterey Bay, CA, results showed that the offshore water masses with the subsurface layer of bioluminescent zooplankton were replaced by water masses advected from the northern coast of the bay with a relatively high presence of mostly non-bioluminescent phytoplankton (Shulman et al., 2011). Offshore observations show a deeper BL potential maximum below the surface layers of high chlorophyll and backscatter values during the earlier stages of upwelling development. Later, the observed deep offshore BL potential maximum disappeared and became a shallower and much weaker signal. Our analysis showed that during the upwelling, bioluminescent dinoflagellates from the northern part of the Bay were able to avoid advection by strong southward currents developed during the upwelling event. Predictive physical, biochemical and bioluminescence intensity models were used to interpret the observed dynamics during the upwelling.

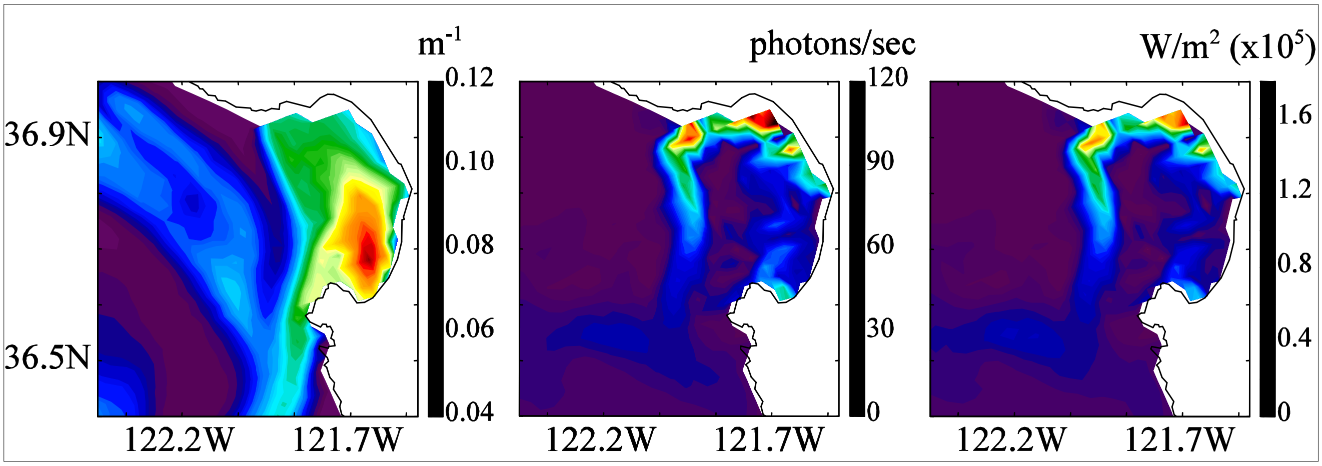

Figure 1. (right) Water-leaving radiance at the surface due to stimulation of the modeled BL potential at 5m depth. The modeled BL potential at 5m depth (middle panel), and a sum of a (absorption) and b_b (backscattering) averaged from the depth of BL potential stimulation (5m) to the surface (left panel).

The results (Figure 1) show high values of BL potential and estimated BLw in areas along the coastline, where high values of BL potential were observed and model-predicted. At the same time, the model showed high values of BL potential along the entrance to the Bay (Figure 1, Shulman et al., 2011), which was not in agreement with observations. In the model, the BL potential dynamics were controlled by advective and diffusive processes only, and as it was speculated in Shulman et al, 2011, the lack of modeling of behavioral dynamics of bioluminescent organisms (as for example, vertical migration of dinoflagellates to avoid advection losses) is responsible for the model's inability to predict the observed weakening of the BL potential along the entrance to the Bay. In Shulman et al., 2012, we tested the hypothesis that vertical swimming behavior explains observed ability of dinoflagellates' to avoid advection by strong currents. The dynamics of dinoflagellates was modeled with the tracer model where the dinoflagellate population is modeled as a concentration, and vertical swimming velocity is introduced into the tracer advective-diffusive-source model. Three swimming behaviors were considered: sinking, swimming to the target depth and diel vertical migration. Swimming velocities in all cases were considered in the range of documented velocities for the dinoflagellates species observed during the upwelling development in the Monterey Bay. Results demonstrated that through swimming behavior, dinoflagellates avoid complete advection out of the Bay during upwelling events (Shulman et al., 2012). With a modeled swimming velocity of 20m/day (a reasonable estimate at half the observed maximum) 40% of the dinoflagellates population was advected from the northern part of the Bay compared to no swimming. This is in agreement with the observed mean BL potential ratio of 0.45 at the Bay entrance compared to the northern part of the Bay. While some of the salient features of short-term changes in BL potential can be predicted and explained with the modeling of advective-diffusive processes, it was demonstrated that the modeling of BL sources and sinks is needed to reproduce the observed spatial and temporal variability of the BL even on short-time scales. It is especially valid in situations when swimming behavior of bioluminescent plankton impacts the BL potential distribution. Continued modeling efforts such as these will gauge the measure of bioluminescence as a tool for integrating ecosystem information, evaluate dynamical optical properties in the ocean, and help in short-term prediction of oceanographic conditions, including BL potential and BLw.

IMPACT/APPLICATIONS

Prediction of the location, timing and intensity of bioluminescence potential is critical for numerous naval operations including preventing detection of covert operations involving submarines, Swimmer Delivery Vehicles and AUVs, as well as in aiding detection of enemy incursions. At present, the Navy does not have capability to forecast BP potential and night time water leaving radiance. The proposed research aims to develop a methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days.

TRANSITIONS

None

RELATED PROJECTS

NRL, RO " Bio-Optical Studies of Predictability and Assimilation for the Coastal Environment (BIOSPACE)" (PI: I. Shulman)

I. Shulman is PI of the NRL project with objectives to improve understanding of the variability and predictability of the underwater light and bio-optical, physical properties on time scales of 1 to 5 days. NRL coupled models and predictions of physical bio-optical properties (including IOPs and BP) are used in our project.

The Multidisciplinary University Research Initiative (MURI) project "Rapid Environmental Assessment Using an Integrated Coastal Ocean Observation-Modeling System (ESPRESSO)" (PIs: O. Schofield, S. Glenn, J.Wilkin, G. Gawarkiewicz, R. He, D. McGillicuddy, K. Fennel, M. Moline).

Objectives of the MURI project are focused on the development of a data assimilative physical-optical modeling-observation system capable of improving predictive skill for forecasting ocean color and improving physical models by using ocean color. M. Moline is Co-PI of the project, and NRL BIOSPACE and MURI project have similar objectives and there are ongoing collaborations between projects.

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